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PECULIARITIES OF THE STRUCTURE, ITS DEFORMATION AND DESTRUCTION OF CONDENSED Cu-Mo-Zr-Y COMPOSITE MATERIAL OF COMMERCIAL PURITY

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The peculiarities of the morphology and structure defects of composite material in the Cu-Mo-Zr-Y system produced from commercially pure raw materials using method of electron-beam evaporation/condensation have been studied. The features of deformation and destruction of the composite have been investigated alongside with its mechanical properties and their change under action of structure defects.

Key words: composite material, structure, mechanical properties, deformation, destruction

Svojstvenost strukture, deformacije i razaranje sprešanog Cu-Mo-Zr-Y kompozitnog materijala. Istraživana je svojstvenost morfologije i strukture grešaka kompozitnog materijala Cu-Mo-Zr-Y dobijena metodom elektro-lučnog isparavanja iz trgovački čistih sirovina. Karakteristika deformacije i razaranje kompozita praćeno je preko mehaničkih svojstava i njihove promjene pod utjecajem grešaka strukture.

Ključne riječi: kompozitni materijal, struktura, deformacija, razaranje, mehanička svojstva

INTRODUCTION

The paper [1] contains results of investigation of the structure and some properties of copper and molybdenum based composite materials and the processing parameters in their production via electron-beam evaporation/condensation.

The present work has been done in connection with the necessity of improvement and repeatability of the properties of condensed molybdenum-copper materials, which particularly arises in the case of using commercially pure initial materials and residual media [2-5].

The aim of the work was to study the peculiarities of the structure and the nature of strength and plasticity of condensed ceramic material of commercial purity.

MATERIALS AND METHODS FOR INVESTIGATION

The object for the investigation was a condensed composite material in the Cu-Mo-Zr-Y system corresponding to the MDK-3 trade with an average molybdenum content of to 12 wt. % and not more than 0,08 wt. % Zr and the same of Y; the rest was copper [1]. The dimensions 1,3x10x50 mm of the samples cut from condensate sheets made it possible to perform an analysis of the macro- and microstructure of surfaces and sections perpendicular to the surface as well as of the phase and chemical composition, hardness, mechanical properties, and features of destruction using optical and electronic scanning microscopy, x-ray diffraction and spectral methods, Auger spectroscopy, and mechanical tension tests in the temperature range 293-1073 K. From 3 to 6 samples were subjected to hardness measurements according to the techniques described in [1].

RESULTS AND DISCUSSION

The investigation of the surface microstructure of the samples established its block character with random or periodic striation of the blocks. The period of repeatability of strips in the latter case changed from 35±3 to 564±32 μm. One of the reasons for the appearance of strips is self-oscillations arising under reducing the rigidity of the system "substrate-edge of tool processing it" [6]. The periodic striation arisen due to self-oscillations is inherited by the condensate at its all dimension levels. There are also technological defects on the condensate surface such as crystallized metal particles ejected out of the melt bath. Even after crystallization these particles can keep the temperature required for melting of the condensate surface material and forming new boundaries (Figure 1a). When ejected at the initial and subsequent stages of the technological process, they distort the crystallization front and thus promote the formation of hillocks on the surface and rods in the volume (Figure 1b) of the condensate.

The study of the microstructure, phase and chemical composition of the section perpendicular to the surface has shown that the simultaneous evaporation of

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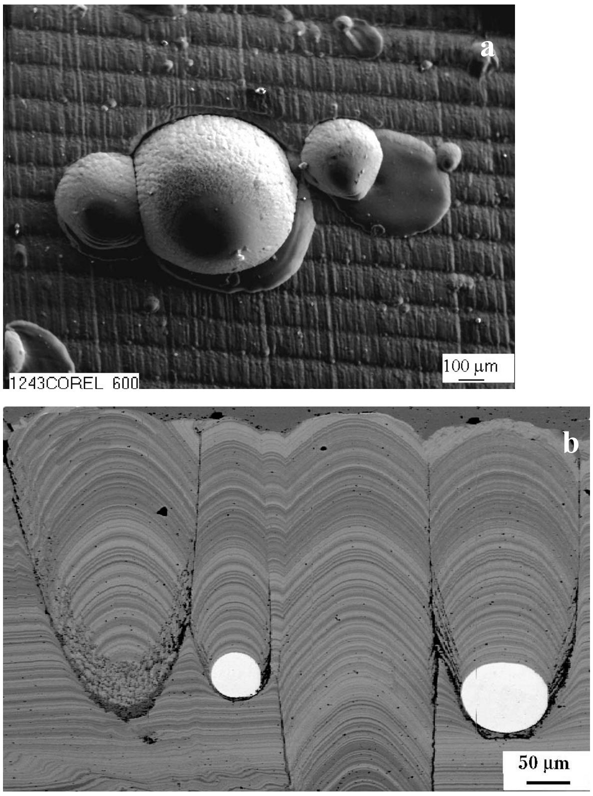

Figure 1. Structure defects produced by ejection of liquid phase: (a) on the surface of condensate; (b) in the volume of condensate.

low-alloyed copper alloy and molybdenum from individual crucibles onto a rotating substrate provides the formation of composite material with a *fcc* matrix and a *bcc* refractory filler in the course of condensation. The filler content varies from 3-5 to 20-24 wt. % and determines a gradient character of the composite. At a molybdenum content of up to 5 wt. %, the composite structure is characterized by discrete slight layered ordering and the refractory filler dispersity from micro- to submicrolevel. When the molybdenum content exceeds 5 wt. %, the condensed composite material has a layered structure at macro-, micro-, and submicrolevels. The layers in the section perpendicular to the surface are wavy corresponding to the surface striation up to the submicrolevel. As a rule, macrolayers have broad boundaries. Each of these boundaries are supposed to correspond to the microlayer formed under abrupt discontinuance in the supply of the main components vapors, and adsorption of impurities from the residual atmosphere in the working chamber. The Auger spectral analysis showed the presence of carbon, sulfur, chlorine, zinc, tin, copper, and molybdenum on the boundary surfaces.

Chemical etching of the condensate section indicates inhomogeneity of the composition and structure of the microlayers. For molybdenum-rich layers, an anisotropic (columnlike) structure is characteristic (Figure 2a), which, according to [7], is formed through joining of atoms from the volumetric diffusion field of the condensed flow to the two-dimensional islandlike layers via diffusion coales-

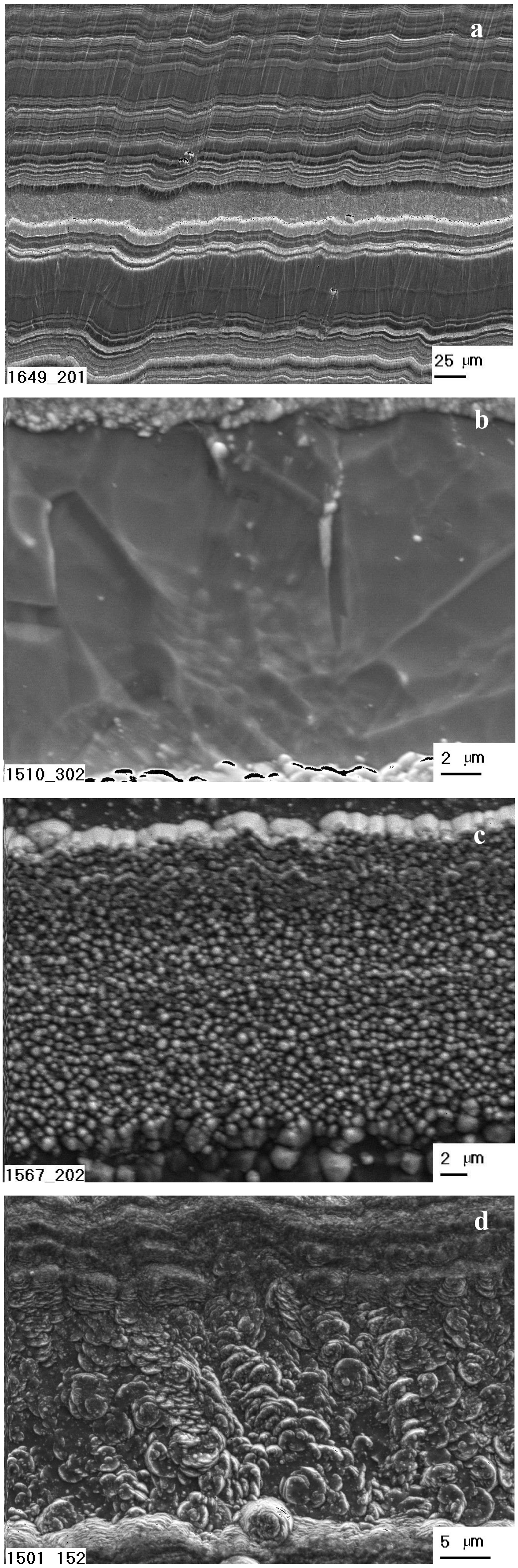

Figure 2. The structure of condensate layers: (a) columnlike; (b) polygonal; (c) with spherical particles;(d) with lenticular particles in the copper-based matrix.

cence. For copper-rich layers, an isotropic structure is predominantly characteristic, which is composed either of disoriented polygonal grains (Figure 2b) or of spherical and lenticular particles dispersed in the *fcc* matrix (Figures 2c, 2d). A detailed analysis of these condensates has permitted us to conclude that the regular form of particles and the corresponding morphology of layers are related to the transformations in copper in the direction vapor – liquid. The lenticular shape of particles may result from the coalenscence of solid-liquid clusters of composite material, the appearance of spherical particles at the moment of approaching the substrate and deformation of them when touching it as well as from the action of the following portions of "drop" vapor. The content of lenticular particles in the condensate layers may change (Figures 2c, 2d). By chemical composition, both lenticular and spherical particles are composites. Chemical etching of the condensate section indicates that depending on the molybdenum content, the refractory component may be present in the composite in the form of either individual grains with a diameter of much smaller than 1 μm or their conglomerates and chains. The x-ray phase analysis of the condensed composite material produced from commercially pure raw material in a medium with residual gases showed that, in addition to the main copper and molybdenum based phases, the material also contains molybdates of the $CuMoO_4$ and $Cu_xMo_yO_z$ type and molybdenum carbides. These data are consistent with the results of the Auger spectral analysis of the sample fracture, which indicate the presence of carbon in the carbide form.

As aforementioned, the formation and composition of condensate are affected by ejection of matter out of melt bathes and its transfer in solid and liquid phases. These matters differ in the composition, ability to cover the condensate surface, and content of impurities. Ejection matter out of the bath with low –alloyed copper melt spread over the surface of the previous layer of the condensate, but the effect on the condensation front and material structure is not localized. The ejections of material out of the bath with molybdenum melt onto the condensate surface are observed in the form of regular spheres or spheroids, which contain, in addition to the main elements Mo, Zr, and Y, impurities C, O, N, and F. The spherical and spheroid particles are held by the previous layer and distort the condensation front of the forming layer. As a result, on the surface of condensed material hillocks are formed whereas in the section defects of different sizes of the cylindrical or conical form, so called "rods", appear with impurity-rich boundaries. The possibility of the rod appearance is also connected with the local inhomogeneity of the distribution of separating layer and the condensate over the substrate.

These rods have boundaries weakened by impurities, which causes a decrease in the strength and plasticity of the condensate during tensile tests. The bigger the length, diameter, and quantity of rods, the more drastic their effect. When the rod length reaches the thickness of sample, the strength of condensate decreases markedly and plasticity falls practically to zero. Therefore rods formed at the initial stages of condensate formation are dangerous defects for the material. The boundaries of condensate microlayers rich in impurities play a similar role: the condensate loses its mechanical properties through sheeting. The nucleation of cracks is frequently connected with cuts on the sample surface. Perhaps, this lead to the decrease in strength and plasticity of condensate with increasing the substrate roughness (which is inherited by the condensate formed on this substrate).

The test temperature also affects the properties of condensate and peculiarities of its destruction. Conditional yield strength, ultimate strength, and hardness were established to monotonically decrease with rising temperature in the range 290-1070 K. The temperature dependences of the plasticity parameters are characterized by extremum which may be attributed to hot brittleness inhered for copper and its alloys [8]. At 900 K the condensate plasticity increases and the character of sample destruction changes. In order to clarify the mechanisms of the condensate plastic deformation and their temperature dependences, we used a thermoactivation analysis for the change in mechanical properties. According to the techniques described in [9], the energy of deformation activation was calculated for condensate and it was higher than that for polycrystalline annealed copper (see Table 1.).

In accordance with papers [9, 10] such an increase in the energy of deformation activation indicates that the mechanism of deformation has changed: dislocation gli-

Table 1. **Activation energy of plastic deformation of the composite material MDK-3 derived from the temperature dependence of the yield strength $Re_{0,2}$ in the range 290-1070 K**

Material	Investigated dependenses	Intervals on the curves	T/Tm for Cu, (Temperature / K)	Activation energy / eV	Note
Cu-Mo-Zr-Y	ln($Re_{02}/T^{1/3}$) from 1/T	1	0,21-0,35 (290-470)	0,09	Experimental data
		2	0,35-0,5 (470-670)	0,25	Calculations after
		3	0,5-0,65 (670-870)	0,60	V. P. Krashchenko,
		4	0,65-0,8 (870-1070)	1,53	V. Ye. Stetsenko [5].
Polycrystalline annealed copper	ln HV from 1/T	1	0,21-0,35	0,05	V. P. Krashchenko, V. Ye. Stetsenko [5] data
		2	0,35-0,5	0,17	
		3	0,5-0,8	0,83	
		4	> 0,8	2,01	

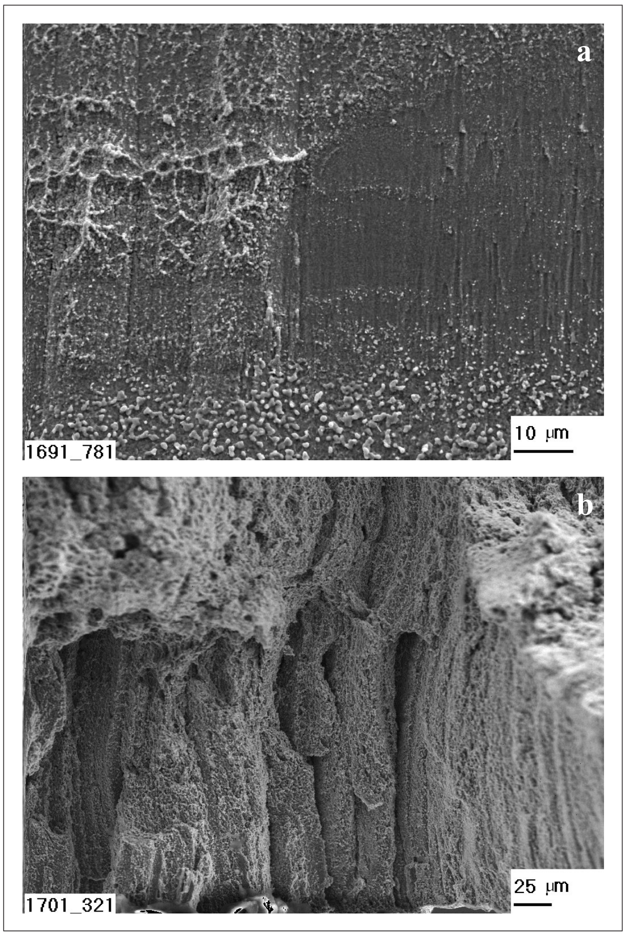

Figure 3. The effect of test temperature on the peculiarities of condensate destruction: (a) in the temperature range of hot brittleness; (b) over 900 K.

de for dislocation climb. The peculiarities of destruction of the condensed composite material during tensile tests also confirm such a change.

It was established by sight that independently of temperature and other test conditions, the destruction of samples of condensed composite material occurs by cut anticipated by plastic deformation. Even in the fracture of the sample tested in the temperature range of hot brittleness, ductile intercrystallite break along the column boundaries is observed (Figure 3a). With rising temperature and changing the mechanism of plastic deformation, the plasticity of the column structure grows accompanied during destruction by enlargement of holes formed in the presence of dispersed particles of refractory filler [11] as well as by splitting of columns and deformation of their fibers (Figure 3b).

CONCLUSIONS

It has been established that under simultaneous evaporation of low copper alloy and molybdenum of commercial purity from different crucibles and condensation them on a rotating substrate, a composite material is formed with a *fcc* matrix and a *bcc* refractory filler whose content varies from 0,3-5 to 21-25 wt.%.

At a molybdenum content of lower 5%, the condensed composite material has a dispersed structure with a refractory component particle size of from micro- to submicrolevel and slight layered ordering.

At a molybdenum content of over 5%, the condensed material acquires a layered structure with a scale hierarchy of layers at the macro-, micro-, and submicrolevels. At all these levels, the layers inherit the peculiarities of the substrate roughness and show up a variety of microlayer structures: columnlike, polygonal, and formed by spherical and or lenticular particles.

Structure defects are formed in condensate of commercial purity due to ejection of liquid phase, distortion of the condensation front, segregation of impurities on different boundaries (of rods, layers, particles), and inherence of the substrate roughness by the condensate layers.

Structure defects of different origin worsen mechanical properties and determine the peculiarities of destruction under tensile test conditions at room temperature.

With increasing plastic deformation temperature, especially in the range over 870 K, the activation energy increases, the mechanism of deformation process changes alongside with change in the peculiarities of destruction and mechanical properties. The increase in the plasticity parameters of condensed composite material correlates with increase of ductile fracture role due to the nucleation and growth of numerous pores

The results obtained make it possible to determine the ways to improvement of technological conditions in production of condensed materials with high and stable properties such as strength, hardness, electrical resistance, and reliability under extreme conditions of operation.

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Note: The responsible translator for English language is author N.J. Grechaniuk.